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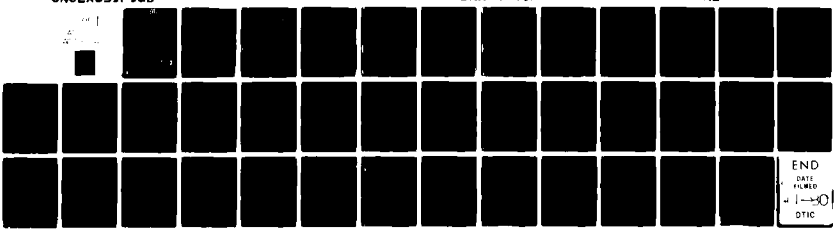

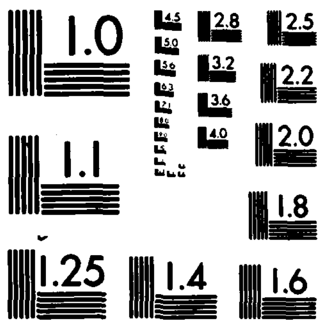

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MISERS BLUFF GROUND SPALL INVESTIGATION

JAYCOR
300 Unicorn Park Drive
Woburn, Massachusetts 01801

10 November 1978

Final Report for Period 1 July 1978—31 October 1978

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20. ABSTRACT (Continue on reverse side if necessary and identify by block number)

This report summarizes the results of an experiment, fielded on MISERS BLUFF II-2 to quantify the driving parameters for observed ground spall. Test objects placed at 10, 20 and 50 psi overpressures were photographically recorded by cameras fielded by the Denver Research Institute. Although test objects were displaced, the recording cameras were either rendered inoperable by the blast, or engulfed in a dust cloud so as to prevent quantitative data acquisition.

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PREFACE

This work was sponsored by the Defense Nuclear Agency under Government Contract No. DNA 001-78-C-0005 and was authorized under Subtask J24AAXXX95903. The DNA's Contracting Officer's Representatives were Major R. Bestgen and Dr. R. C. Webb.

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I. INTRODUCTION

This report describes the fielding of an experiment on the MISERS BLUFF Phase II events to quantify the driving parameters behind a shock-driven ground spall phenomenon observed on Phase I events. A detailed background for the experiment is presented in Section II, while the next sections provide details on the deployment of the experiment and the subsequent data acquisition.

The report concludes by recognizing that the primary data acquisition instrumentation (cameras deployed by the Denver Research Institute) did not acquire any information because the events created dust clouds which completely obliterated the test areas. The secondary data, net disc displacement, is reported to be too sparse, and to have too much scatter, to permit the derivation of valid correlations. The report concludes with a recommendation that the measurement be attempted again on the next series of explosive events, or perhaps that a small experiment be mounted to obtain similar information from a laboratory shock tube.

II. BACKGROUND

On several of the MISERS BLUFF Phase I events, cameras were deployed in photographic stations set up at distances from the detonation corresponding to 20 and 10 psi blast overpressures. These stations were set up to photographically record impacting ejecta and to observe the anticipated build-up of ejecta and debris against simulated structures. The cameras were aimed perpendicular to shot radials and the camera fields of view contained I beams and simulated structures. Because of previous photographic work on similar events, it was recognized that explosive events of this type generate severe dust problems. To minimize this dust and to assure that the impacting ejecta would be recorded, the area between the detonation and the camera stations, and also the area around the camera stations, was treated with a latex dust suppressant.

The latex dust suppressant did its job quite well. The shot-induced dust was held to an absolute minimum and good photographic data was obtained on the impacting ejecta. As a result of this dust suppressant treatment, however, an excellent record of another shot-driven phenomenon was obtained.

It has been recognized that the passage of the ground shock and/or air shock can disturb the ground surface. On these particular events, the dust suppressant allowed the cameras to photographically record the upward spall of chunks of surface material. This surface material was undoubtedly held together by the latex suppressant but it is felt that a similar cohesiveness could be generated by soil moisture, vegetation or other such variables. In Phase I events, these chunks of soil material were observed leaving the ground with upward velocities as high as 20 to 30 feet per second.

Since similar camera stations were to be utilized on the MISERS BLUFF Phase II events, it was proposed that an attempt be made to quantify the driving parameters behind this spall phenomenon. Although the Phase I photography allowed the quantization of velocity vectors, the lack of definition of the size, and particularly the mass of the spalled material, prevented any interpretation or bracketing of the driving parameters.

In this experiment, test objects of varying mass, and mass-to-area ratio, were placed in the field of view of appropriate recording cameras. It was anticipated that trajectory data which could be obtained from the recorded imagery would then be used in an attempt to quantify the driving parameters for the ground spall. A preliminary fielding of these test objects was attempted on the first event of Phase II. The discs were fabricated and emplaced by CERF personnel, but the large amount of dust created by the event prevented photographically recording any motion even though significant post-shot displacement was observed. On the second event, JAYCOR personnel fielded the experiment and the ground surface received an increased latex treatment. Although a considerable decrease in dust effects was observed, enough dust was again lofted in this event to obliterate any desired photographic records.

III. EXPERIMENT OVERVIEW

The MISERS BLUFF II-1 and II-2 events were detonated at the Planet Ranch near Lake Havasu, Arizona. The first event of Phase II was the detonation of 120 tons of ANFO on 28 June, 1978. The second event was the simultaneous detonation of six 120 ton ANFO charges in a hexagonal array, on 30 August, 1978.

This spall experiment was fielded in conjunction with experiments already designed and configured by CERF to examine various aspects of impacting ejecta and debris buildup. The cameras in the photographic stations at 50, 20 and 10 psi over-pressures were fielded by the Denver Research Institute (DRI). These cameras were Millican cameras equipped with 13 mm lenses, and as such, they had approximately a 50 degree field of view with a depth of field that ranged from approximately 2 to 20 meters.

The camera stations used on the first event were C-27, C-28 and C-30. These respective stations, shown on Figure 1, were located nominally at 315, 440 and 570 feet from the detonation. The camera stations on the second event were located at similar distances from stack 3 of the hexagonal array, along a stack radial but not an array radial. These locations are shown in Figures 2 and 3 (supplied by K. Benson of CERF). The detailed layout of each of these camera stations is described in the following section together with a description of the location for the test objects placed in the fields of view of these cameras.

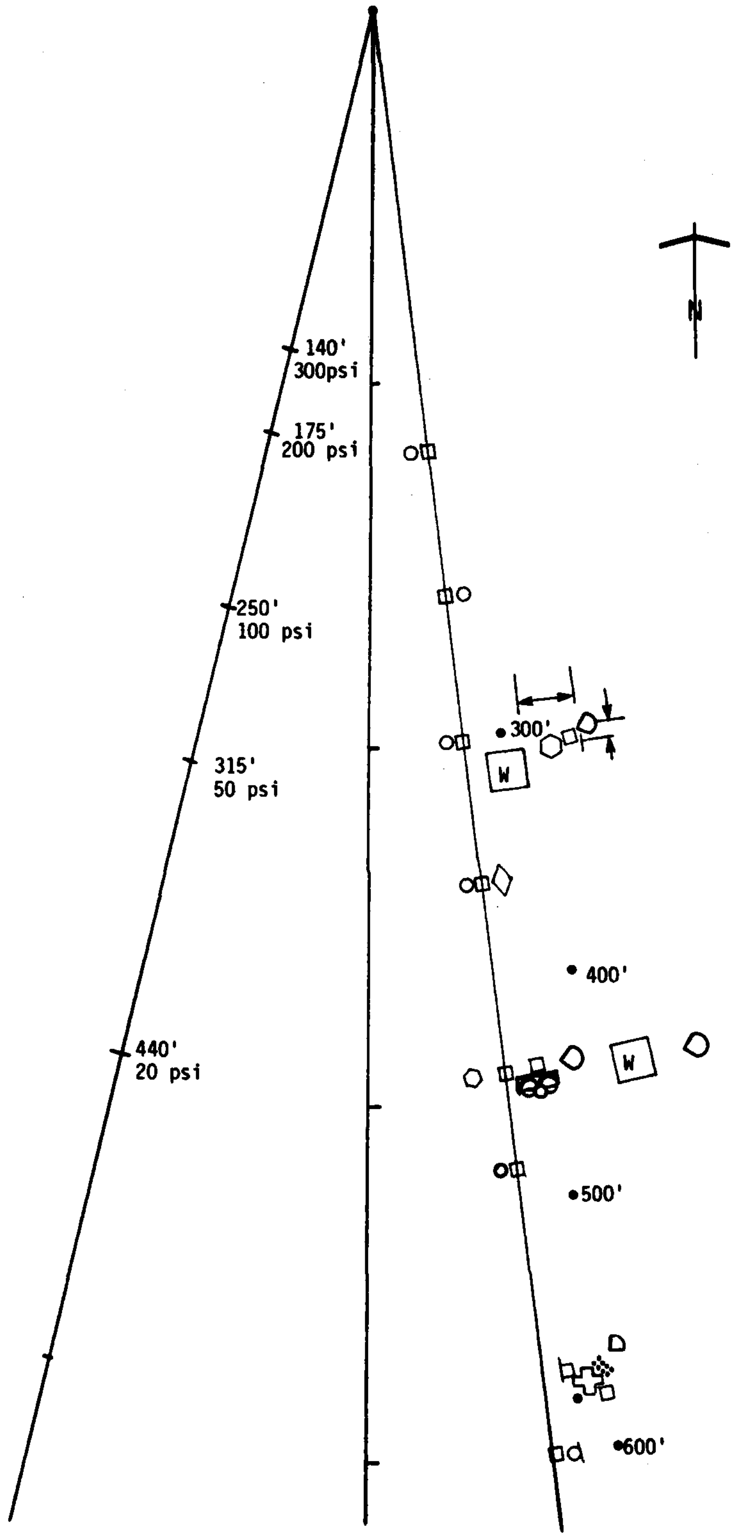


Figure 1. Overview of CERF Radial for MISERS BLUFF II-1
Showing 50, 20 and 10 psi Station Locations

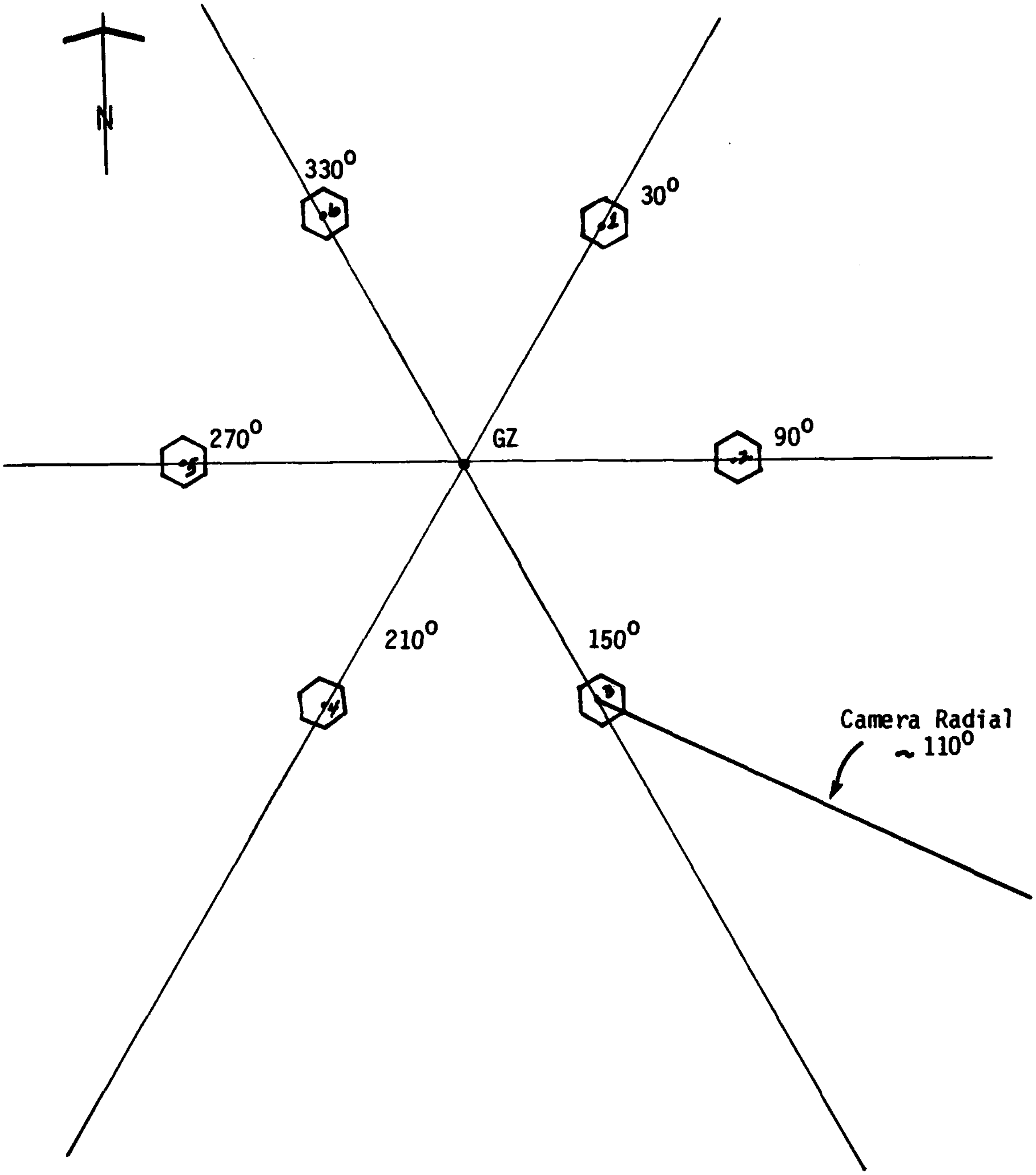


Figure 2. Event MB-II-2 Overview with Location of CERF Camera Radial

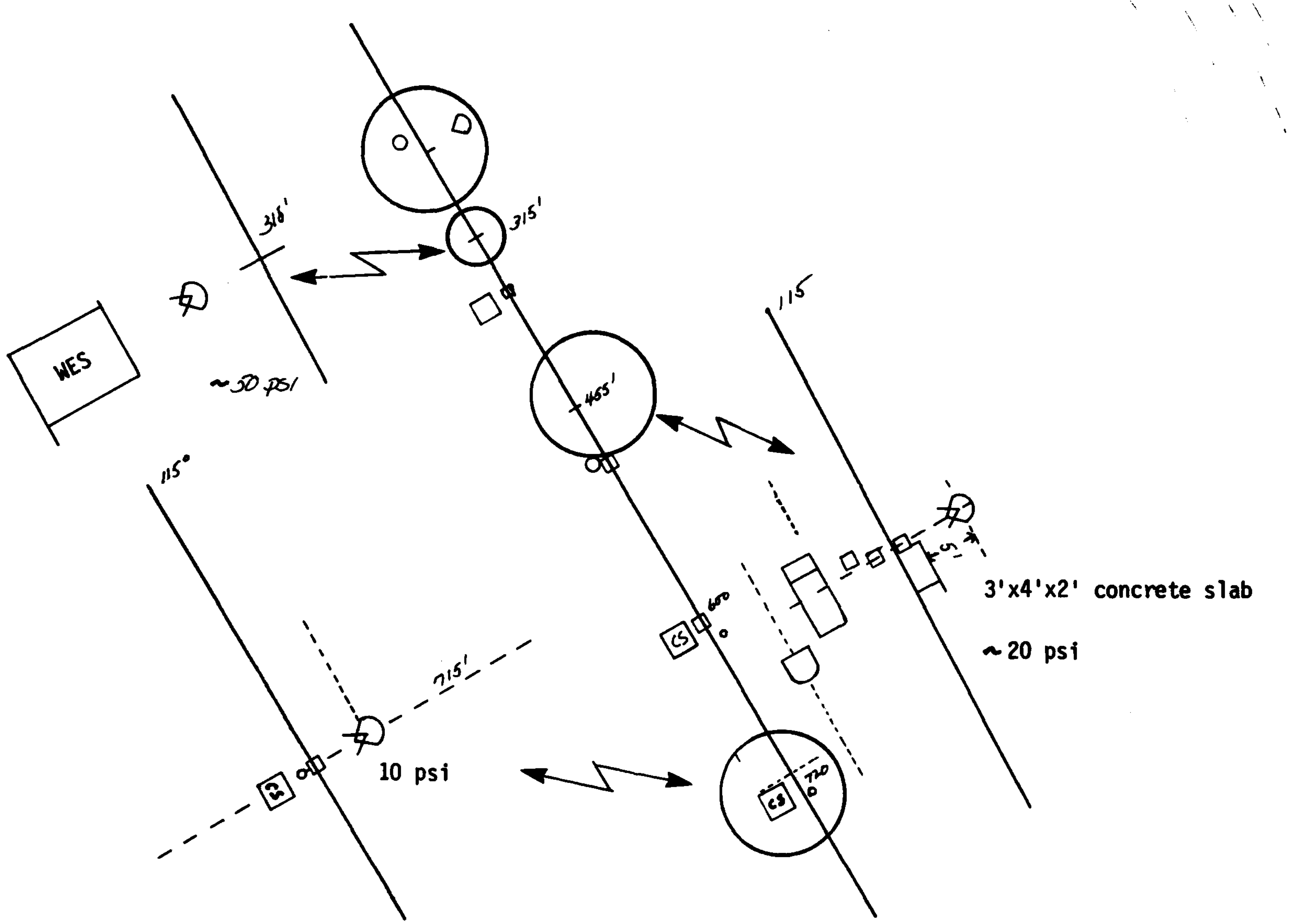


Figure 3. Detailed Fielding Diagram for MB-II-2 Showing 50, 20 and 10 psi Stations.

IV. EXPERIMENT CONFIGURATION

Figures 4, 5, and 6 present detailed layouts of the 50, 20 and 10 psi camera stations utilized in the first event. Although there were some slight modifications made to these station locations, it is out understanding that they were generally as depicted on each of these figures the location for the spall experiment is indicated in distance from the camera station. The emplacement of test discs was intended to be identical at all three camera stations but there was considerable deviation from this planned deployment.

Figures 7, 8, and 9 present layouts of the stations used on the second event. Here the locations of the spall experiments are as fielded. this experiment was one of the last emplaced and it was, therefore, fielded at locations of opportunity, between existing ejecta measurement devices.

Test Discs

To quantitatively assess the driving parameters behind the ground spall, test discs of varying mass, and mass-to-area ratio, were deployed in the field of view of the recording cameras. These discs were fabricated out of aluminum and steel and were color coded, numbered and accurately weighed. The color coding was accomplished with a simple application of spray paint. Each disc was also numbered by stamping it with a number punch. After both color coding and numbering were completed, the test discs were weighed and the weight recorded for each disc.

The size of the discs used in this experiment were a compromise between being small enough to be affected by the anticipated driving parameters and being large enough to be photographically recorded by the cameras. Figure 10 presents cross sections of the 18 discs deployed on this experiment. Note that all of the discs are basically 0.5 cm thick with a certain fraction of them being hollowed out. Table I summarizes nominal parameters for all the test discs while Table II lists measured weights.

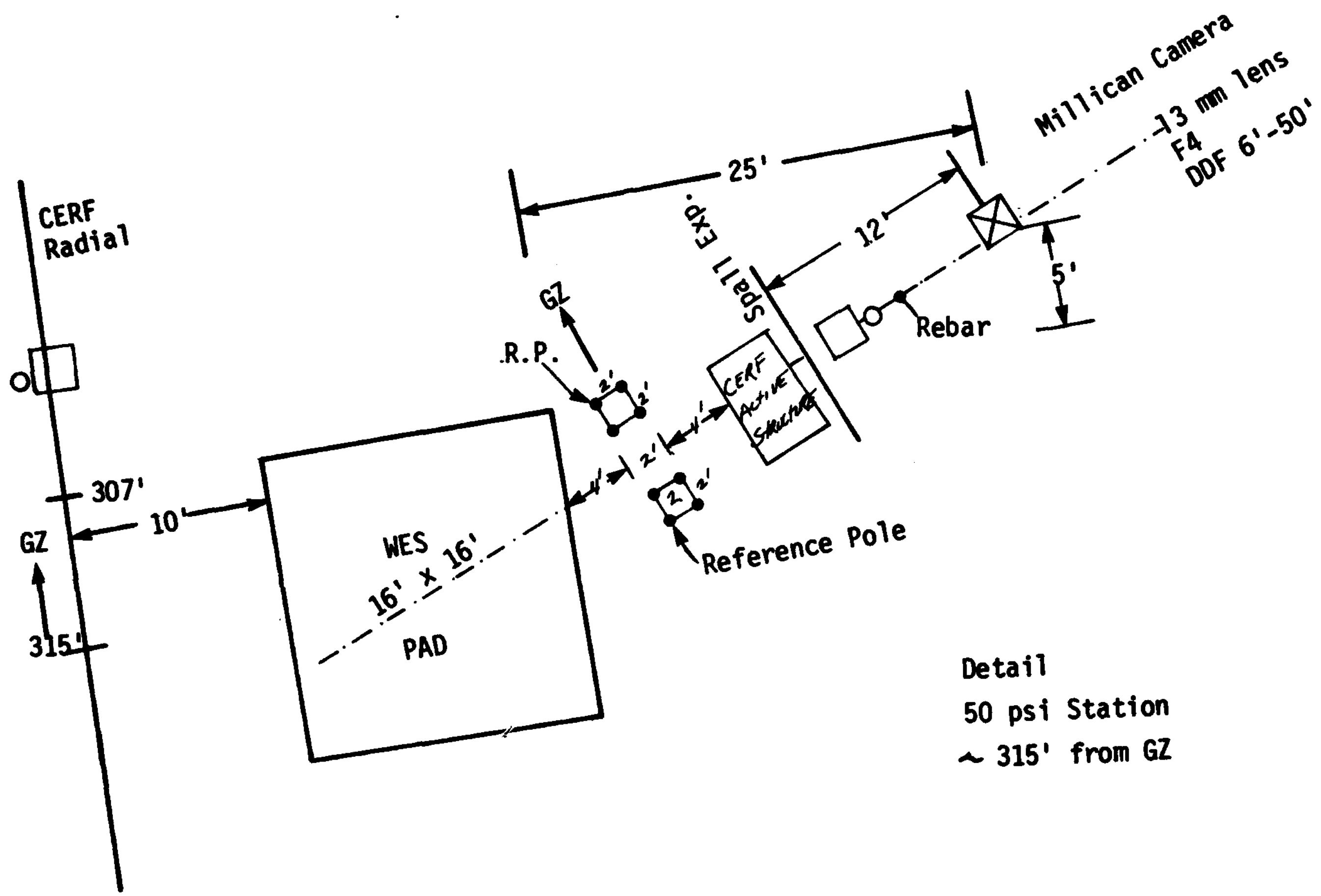


Figure 4. Location of Spall Experiment at Camera Station C-27 (50 psi) on MB-II-1.

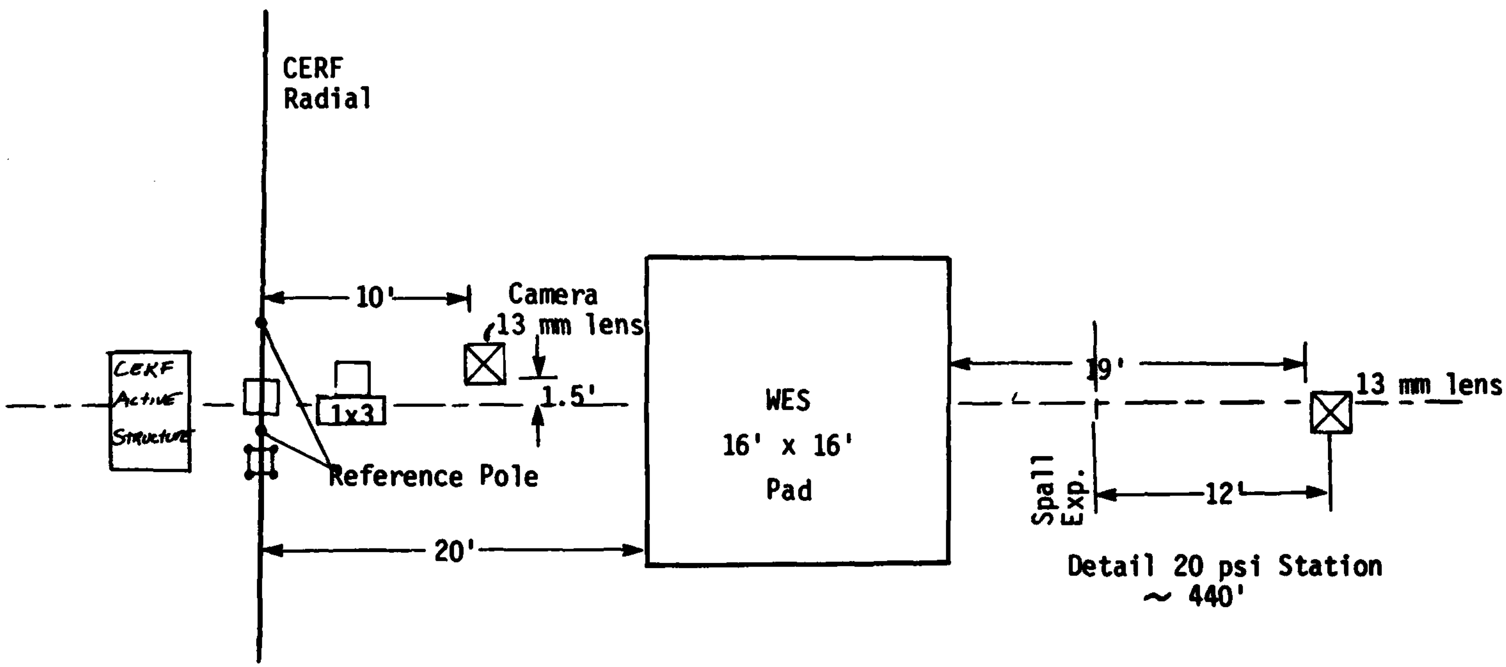


Figure 5. Location of Spall Experiment at Camera Station C-28 (20 psi) on MB-II-1.

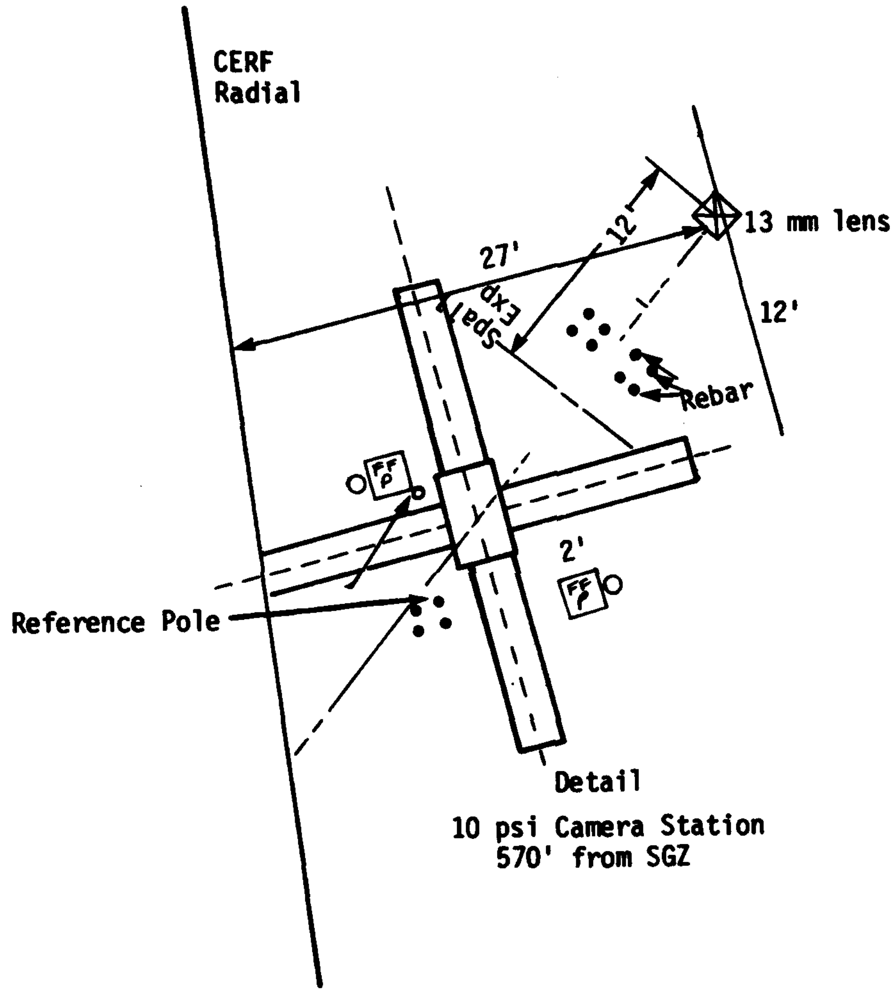


Figure 6. Location of Spall Experiment at Camera Station C-30 (10 psi) on MB-II-1.

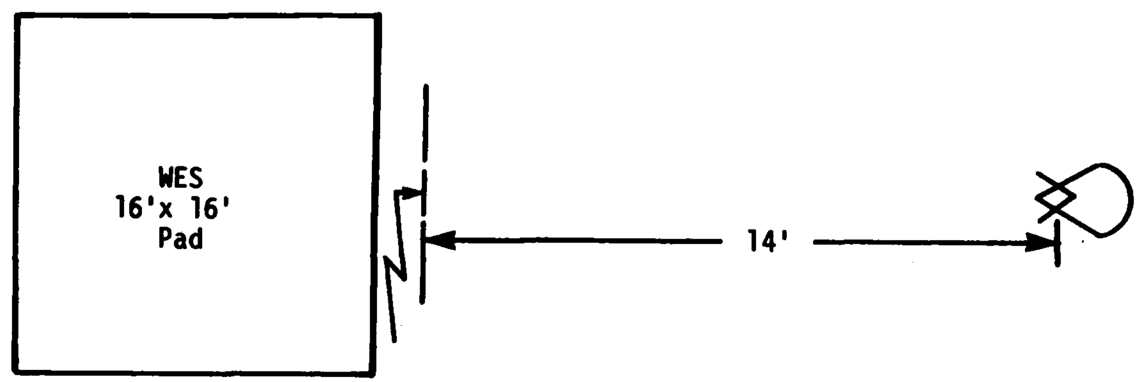


Figure 7. Location of Spall Experiment at 50 psi Station on MB-II-2.

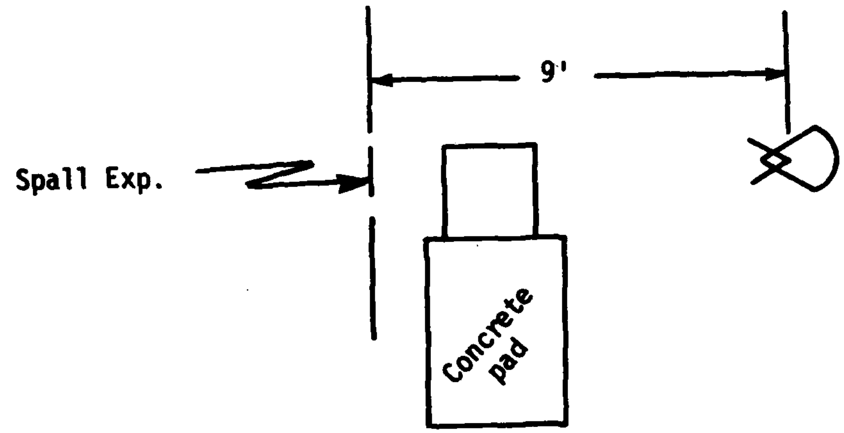


Figure 8. Location of Spall Experiment at 20 psi Station on MB-II-2.

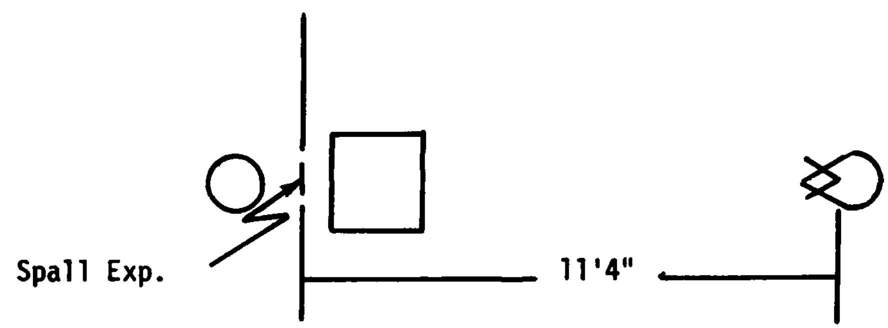


Figure 9. Location of Spall Experiment at 10 psi Station on MB-II-2.

Disc Emplacement

Figure 11 shows the emplacement pattern used for the eighteen test discs fielded in front of the three camera stations utilized in this experiment. The discs were nominally placed perpendicular to the recording camera's optical axis at a spacing of approximately 5 cm. Note that exact distance was not critical but that final position was measured prior to the shot. Note also that all discs were emplaced so that their upper surface was flush with the ground surface. Those discs which were hollowed out were emplaced with the hollow side down. The tabular summary on the left hand side of Figure 11 identifies where each disc was placed for each camera station.

The latex dust suppressant cemented together the top 1/8 to 1/4 inch of soil. This cementing was capitalized on by using a sharp X-acto knife to cut out a disc of cemented soil just larger than each test disc and the test disc was then placed in the resulting void. Soil was either added or subtracted, as necessary, to assure that the surface of the test disc was flush with the soil surface at the time of the event. Each void was cut just large enough to ensure that the test discs were quite free to move vertically.

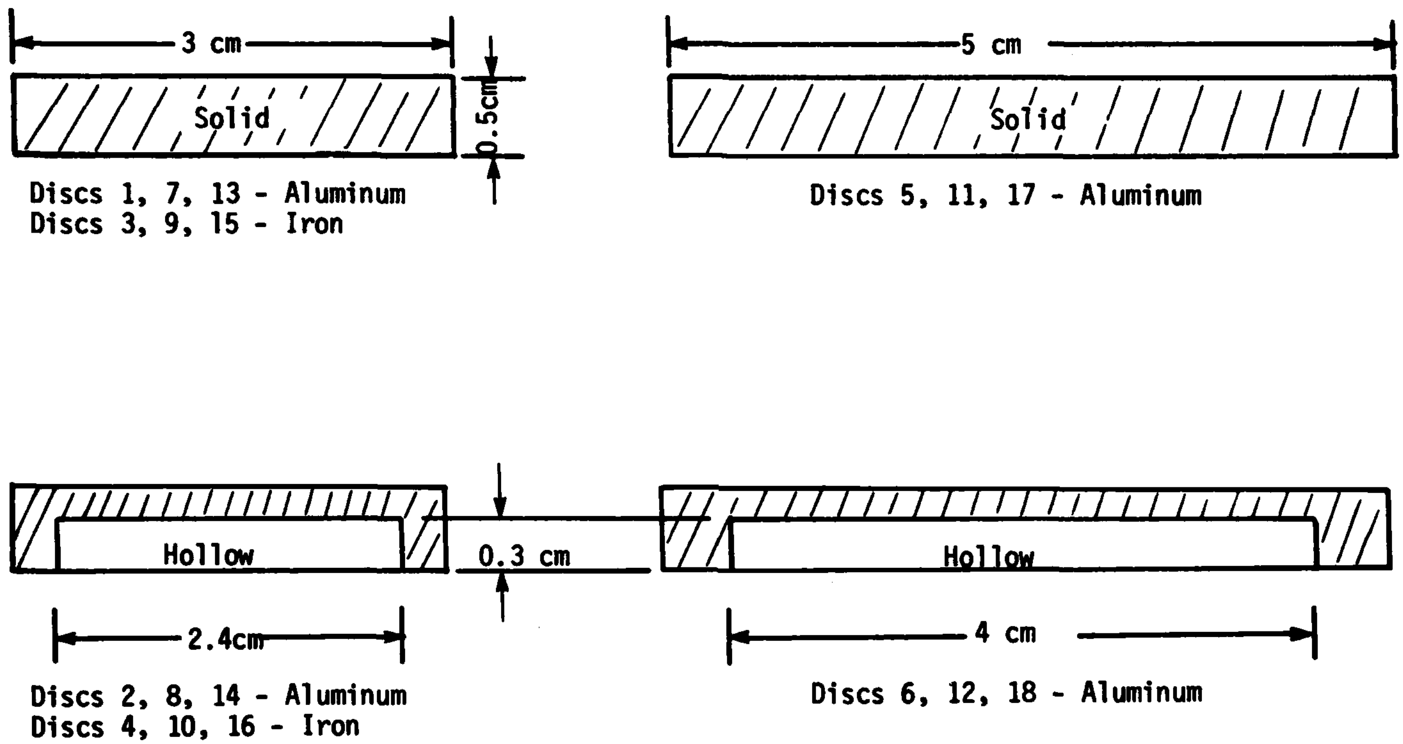


Figure 10. Dimensional Cross-Sections of Circular Test Discs for Ground Spall Assessment Experiment (All discs 0.5 cm thick, drawings are double scale).

Test Disc Number: Camera Station 50 psi	20 psi	10 psi	Color
1	7	13	Red
2	8	14	Green
3	9	15	Blue
4	10	16	Yellow
5	11	17	White
6	12	18	Black

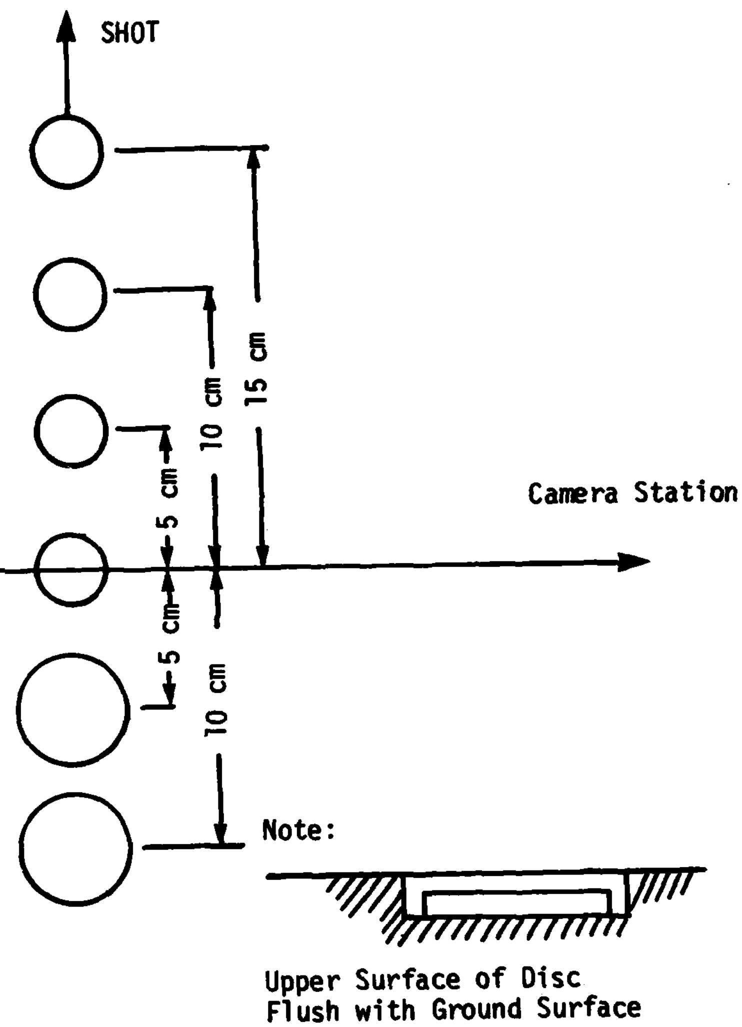


Figure 11. Test Disc Emplacement Summary for MISERS BLUFF Phase II Events

TABLE I

TEST DISC SUMMARY
(all discs 0.5 cm thick)

DISC NUMBER	MATERIAL	COLOR	DIAMETER (cm)	SOLID/HOLLOW	NOMINAL MASS (gm)
1, 7, 13	Al	Red	3.0	S	9.5
2, 8, 14	Al	Green	3.0	H	5.9
3, 9, 15	Fe	Blue	3.0	S	26.5
4, 10, 16	Fe	Yellow	3.0	H	16.3
5, 11, 17	Al	White	5.0	S	26.5
6, 12, 18	Al	Black	5.0	H	16.3

TABLE II

TEST DISC WEIGHTS

DISC NUMBER	MATERIAL	DIAMETER (cm)	Mass (gm)
1	Al	3	9.98
2	Al	3	6.14
3	Fe	3	27.71
4	Fe	3	17.11
5	Al	5	28.08
6	Al	5	17.27
7	Al	3	10.01
8	Al	3	6.23
9	Fe	3	27.55
10	Fe	3	17.14
11	Al	5	27.91
12	Al	5	17.54
13	Al	3	9.98
14	Al	3	6.18
15	Fe	3	27.61
16	Fe	3	16.92
17	Al	5	27.78
18	Al	5	17.19
1A*	Al	3	27.04
3A*	Fe	3	9.94

* Replacements for discs 1 and 3, lost on event #1.

V. POST-SHOT MEASUREMENTS

Post-shot measurements on this experiment can be divided into two kinds -- net disc displacement measurements which were made immediately after the event and disc trajectory data (the primary data sought) which would be obtained some weeks after the event from the processed DRI photography. Each of these is discussed below in more detail

Disc Trajectory Data

Disc Trajectory data, the primary data sought in this experiment, was to have been obtained from detailed analysis of dimensional measurements made in a frame-by-frame examination of the DRI photography. As mentioned previously, however, these events created extremely large and dense dust clouds because of the make-up of the surface soil in the test area. These dust clouds completely obliterated any view of the experimental area and, although the test discs could be observed in pre-shot frames, not one frame recording disc displacement was obtained from either event. Observations are, therefore, limited to net displacements.

Net Displacement Measurements

Disc displacement was observed on both events, although not at all camera stations and not for all discs. Observed displacements are summarized below for each event:

MB-II-1

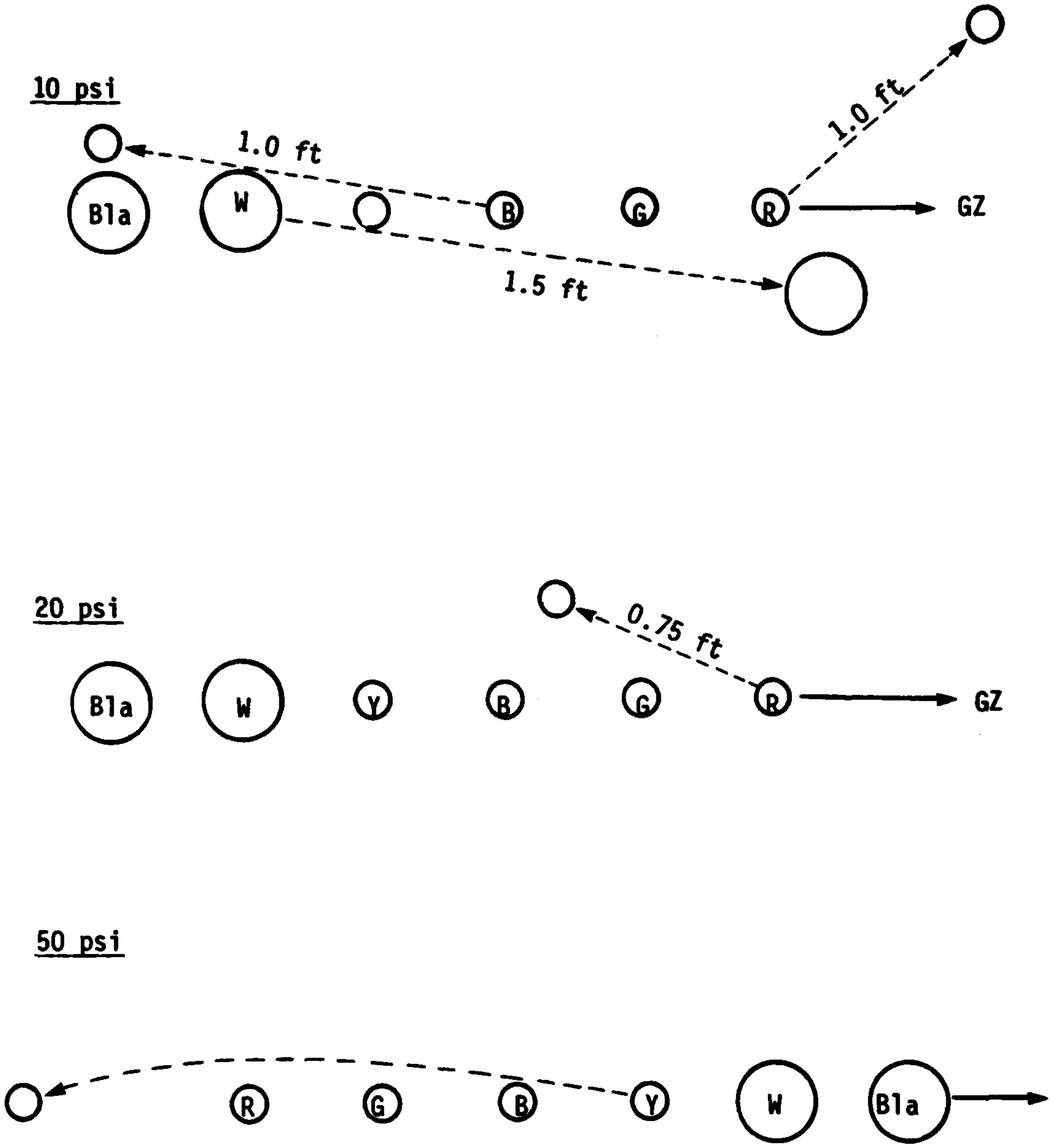
As mentioned previously disc emplacement, and post-shot measurement, for this event was done by CERF personnel. The post-shot displacement data was obtained from photographs taken the following morning. Maximum observed disc displacement (at 50 psi) was about 2 feet, except for the fact that two discs were never recovered. Recorded disc displacements are summarized in Figure 12. Please refer to Figure II and

Table I for specifics on disc emplacement and sizes.

It should also be noted here that after disc emplacement the test area received another light dust suppressant treatment. Post-shot observations revealed that some of the discs had actually been cemented in place by this last treatment, and that others had considerable chunks of soil cemented to them. In general, this would imply that pre-shot conditions were at best uncertain, and that acquired information must be examined with this in mind.

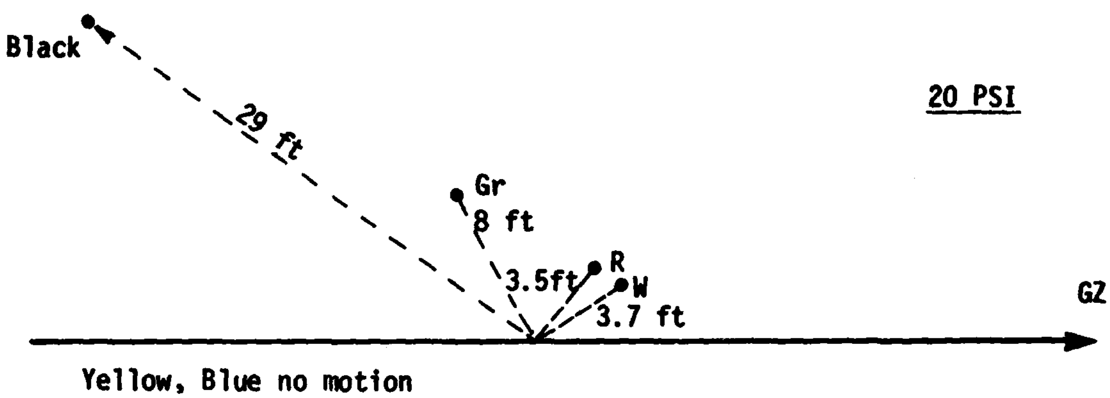
MB-II-2

For this event, disc displacement was measured only at the 50 and 20 psi stations. There was no discernible displacement at the 10 psi station. Measured disc displacements were considerably larger than on the first event, and ranged from 3 to 50 feet. Measured disc displacements are shown in Figure 13.



Note: Red and Blue never found.

Figure 12. Recorded disc displacement on even MB-II-1



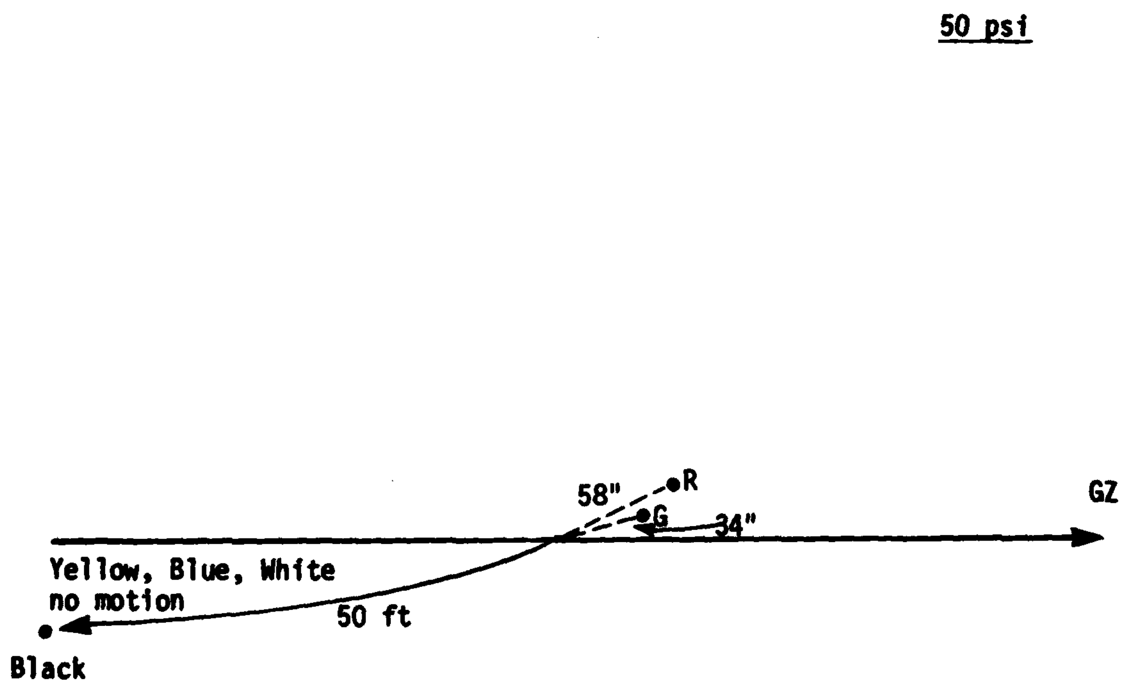


Figure 13. Recorded disc displacement on even MB-II-2.

VI. RESULTS

As mentioned previously, the prime data source for this investigation was to have been the photography obtained by DRI. Obliteration of these records by the dust cloubs created in the detonations also eliminated the data sought. The only data available, from which some information may be gleaned, is the net displacement data described in Section V. This data is reviewed below and bounding values are assigned to dynamic parameters of interest.

A review of Figures 12 and 13 will show that there was no preferred direction of motion on event 1 but that on event 2, disc displacement was primarily away from charge towards an array radial. This movement may be due to the secondary arrival of a shock from charge 2 (an effect readily seen on the photography from the change in direction of moving dust) once the shock from charge 3 had already lofted the discs. This, however, is pure speculation and can in no way be validated. It is also interesting to realize that while net displacements on event 2 were considerably greater than those observed on event 1, there was no observable disc displacement at 10 psi, whereas 3 discs were displaced on event 1 at this same anticipated overpressure.

The only quantitative data obtained from both events was net disc displacements measured after the events. To examine this information, the equations of motion for a moving disc were considered. The effects of drag were not considered because of the uncertainties in the acquired data and because of the fact that inclusion of these effects would greatly complicate the problem because of unknowns in assigning accurate vector quantities and directions. The equations of motion for a disc ejected at velocity V and at an angle θ from the horizontal, are given by:

$$x = V \cos \theta t, \text{ and} \tag{1}$$

$$y = V \sin \theta t - \frac{g}{2} t^2 , \tag{2}$$

where x and y are horizontal and vertical displacements measured from the original disc location, g is the force of gravity and t is elapsed time. Note that at t=0, y=0 and that the next time y=0 (at impact),

$$t = \frac{2\,V \sin\theta}{g} \quad . \tag{3}$$

Assuming then no roll, the next horizontal disc displacement at impact is given as:

$$x = \frac{2\,V^2 \sin\theta \cos\theta}{g} \quad . \tag{4}$$

Noting that $\sin 2\theta = 2 \sin\theta \cos\theta$, and that x is measured as net displacement, we have

$$V = \sqrt{\frac{gx}{\sin 2\theta}} \, . \tag{5}$$

With this expression, and assuming an ejection angle, the initial disc velocity may be estimated. Note also, that this expression yields a minimum value for V, at $\theta = 45^\circ$, and that minimum ejection parameters may be estimated as:

$$\text{Minimum Velocity} = \sqrt{gx} \tag{6}$$

$$\text{Minimum Momentum} = m\sqrt{gx}, \text{ and} \tag{7}$$

$$\text{Minimum Kinetic Energy} = \frac{mgx}{2} \tag{8}$$

where m is the disc mass.

The results of interpreting the displacement data in terms of Equations 6, 7, and 8 are summarized in Table III. Note that inferred velocities range from approximately 5 to over 30 feet per second with a substantial grouping in the 10 to 15 feet per second range. Again, the higher displacement, and velocities, for event 2 are apparent.

Figure 14 shows inferred ejection velocities as a function of assumed ejection angle and measured displacement. The relative minimum at 45° is apparent, as is the fact that inferred velocities are relatively insensitive to ejection angle until 75 to 80 degrees is reached. These latter ejection angles, or greater, are probably more realistic (almost vertical), but here relatively small changes in assumed angle imply large changes in inferred ejection velocity.

TABLE III

SUMMARY OF DISC DISPLACEMENT DATA

Event	Disc#	Mass (gm)	Overpressure	Displacement (cm)	Velocity	Inferred Minimum Momentum	Inferred Minimum Energy
1	13	9.98	10	30	171	1,711	146,700
1	15	27.61	10	30	171	4,734	405,867
1	17	27.78	10	46	212	5,898	626,161
1	7	10.01	20	23	150	1,503	112,813
1	4	17.11	50	46	212	3,633	385,659
2	7	10.01	20	102	316	3,165	500,300
2	8	6.23	20	244	489	3,046	744,859
2	11	27.91	20	114	334	9,329	1,559,053
2	12	17.54	20	884	931	16,326	7,597,626
2	1A	27.04	50	147	380	10,263	1,947,691
2	2	6.14	50	86	290	1,783	256,740
2	6	17.27	50	1524	1222	21,106	12,896,545

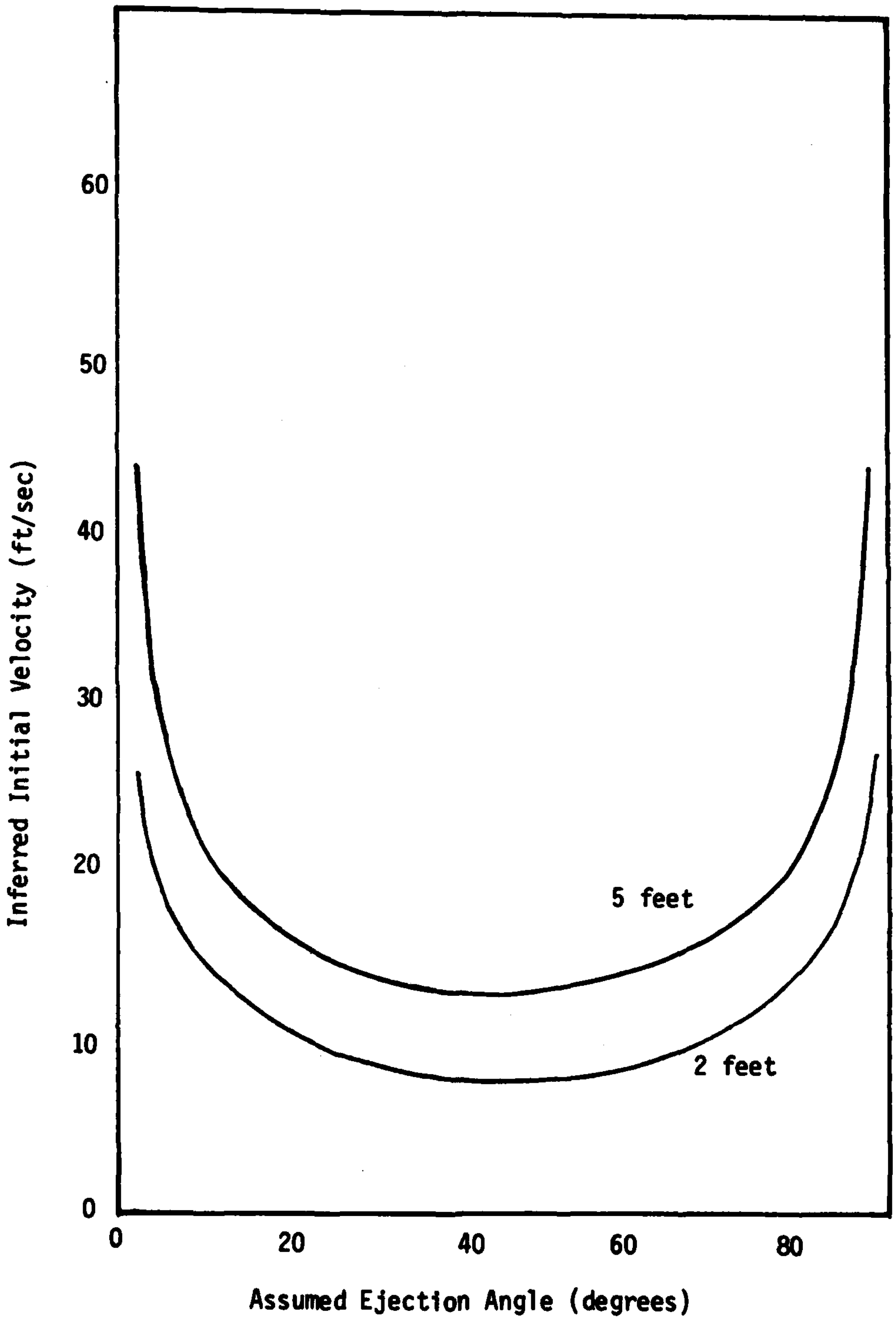


Figure 14. Inferred Disc Ejection Velocity as a Function of Measured Displacement and Assumed Ejection Angle.

The data shown in Table III has been examined and attempts made at deriving correlations with projected driving parameters. Unfortunately, the small amount of data, and the extreme scatter in values, has prevented deriving any statistically significant correlations. It is felt that one of the largest uncertainties associated with the data, post-impact motion due to rolling and/or bouncing, has probably made the successful derivation of such correlations almost impossible. This movement cannot be accounted for in any way and the lack of photographic data becomes an even more important consideration.

VII. RECOMMENDATIONS

Although this investigation was not as successful as was hoped, the lack of data to interpret was due to effects which were not adequately controlled and not under the specific jurisdiction of this program. The information sought still has relevance to specific phenomenology and systems questions. As such, it still is important that the effect be quantized and that further effort be expended in doing this. It is recommended that the acquisition of the required information be obtained in one of two ways, or perhaps both:

A. A limited series of shock tube tests could be conducted wherein cameras could view treated soil samples, through access ports, while controlled shocks were passed over them.

B. An identical effort could be mounted on the next series of HE events where ejecta impact photography is to be obtained. It is understood that future tests will be conducted at sites where soil types are more conducive to successful control with the latex suppressant and that obliteration of the field-of-view is not likely.

C. A detailed program could be mounted which incorporates both of the above suggestions. Here, preliminary shock tube experiments could be used to better define test disc geometry and coupling conditions to more effectively acquire the sought for information.

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Air Force Weapons Laboratory
Air Force Systems Command
ATTN: NTED, J. Renick
ATTN: NTE, M. Plamondon
ATTN: SUL
ATTN: NTED

Assistant Chief of Staff
Intelligence
Department of the Air Force
ATTN: INT

DEPARTMENT OF ENERGY

Department of Energy
Albuquerque Operations Office
ATTN: CTID

Department of Energy
Nevada Operations Office
ATTN: Mail & Records for Technical Library

OTHER GOVERNMENT

Central Intelligence Agency
ATTN: OSI/NED, J. Ingley

Department of the Interior
U.S. Geological Survey
ATTN: D. Roddy

DEPARTMENT OF ENERGY CONTRACTORS

Lawrence Livermore National Laboratories
ATTN: Technical Information Dept Library

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Oak Ridge National Laboratory
ATTN: Civ Def Res Proj, Mr. Kearny

Sandia National Laboratories
ATTN: Doc Con for Library & Security Class Div

Sandia National Laboratories
ATTN: L. Vortman
ATTN: A. Chaban
ATTN: 3141

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Aerospace Corp.
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Artec Associates, Inc.
ATTN: D. Baum

BDM Corp.
ATTN: T. Neighbors
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Boeing Co.
ATTN: Aerospace Library
ATTN: B. Lempriere

California Research & Technology, Inc.
ATTN: K. Kreyenhagen

Civil Systems, Inc.
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Develco, Inc.
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EG&G Washington Analytical Services Center, Inc.
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Electromechanical Sys of New Mexico, Inc.
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University of New Mexico
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H-Tech Labs, Inc.
ATTN: B. Hartenbaum

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ATTN: Documents Library

JAYCOR
ATTN: H. Linnerud

Kaman Sciences Corp.
ATTN: D. Sachs
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Merritt Cases, Inc.
ATTN: Library
ATTN: J. Merritt

Nathan M. Newmark Consult Eng Svcs
ATTN: N. Newmark
ATTN: W. Hall

Physics Applications, Inc.
ATTN: C. Vincent

Physics International Co.
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ATTN: F. Sauer/C. Godfrey

R & D Associates
ATTN: Technical Information Center
ATTN: J. Lewis
ATTN: C. MacDonald
ATTN: P. Haas

Science Applications, Inc.
ATTN: Technical Library

Science Applications, Inc.
ATTN: J. Dishon

Science Applications, Inc.
ATTN: B. Chambers, III

Science Applications, Inc.
ATTN: K. Sites

Southwest Research Institute
ATTN: A. Wenzel
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SRI International
ATTN: B. Gasten/P. De Carli
ATTN: G. Abrahamson

Systems, Science & Software, Inc.
ATTN: D. Grine
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Terra Tek, Inc.
ATTN: S. Green

TRW Defense & Space Sys Group
2 cy ATTN: P. Dai
ATTN: Technical Information Center

TRW Defense & Space Sys Group
ATTN: E. Wong

DEPARTMENT OF DEFENSE CONTRACTORS (Continued)

Weidlinger Assoc., Consulting Engineers
ATTN: M. Baron

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